Challenges

The key technology challenges facing Fly & Play operations today involve coordination of geographically dispersed ground operations and efficient decision making based on the massive amounts of data produced during spaceflight. The challenges will become more complex as spaceports manage multiple, simultaneous missions in the future.

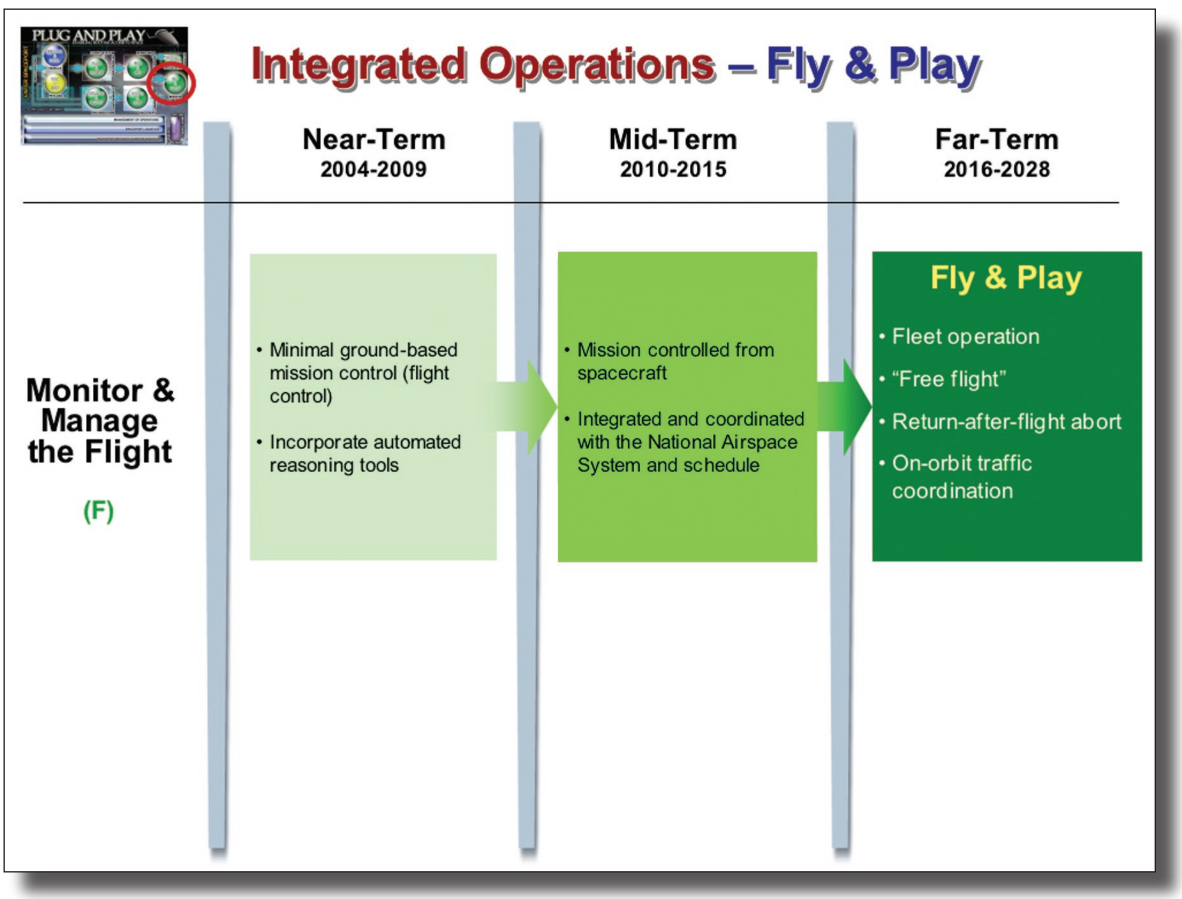


Figure 26. Fly & Play functional capabilities roadmap summary

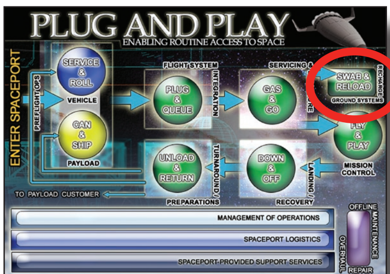
Technical Approaches

New technologies that improve the situational awareness of ground and flight crewmembers are essential to realize this concept. Additional enhancements include orbital-based monitoring of vehicles, artificial intelligence in spatial awareness and control efforts, and enhanced cybernetic interfaces. Furthermore, the capability to accommodate contingency management actions during a declared flight emergency must be ensured in the mission support phase. This phase will emphasize the ability to prioritize vehicle operations via vehicle and ground automation in order to optimize safety margins during flight emergencies. Table 7 summarizes the key technologies associated with Fly & Play. A more detailed description of the challenges and technical approaches can be found in Appendix I.

Table 7. Key challenges and technologies for Fly & Play

Challenges	Spaceport Technologies
• Coordinating and automating decision making is necessary for operational concepts involving geographically distributed ground control operations • Transforming data into real-time information for situational awareness and decision making • Maintaining a continuous state of readiness for a variety of flight abort scenarios is needed for all phases of flight and all vehicle types • Making in-space communications readily available at a low cost is a critical part of the necessary space transportation infrastructure backbone	• Advanced planning and scheduling tools – Dynamic scheduling – Situational awareness – Human-machine interfaces – Intelligent software agents • Advanced decision support tools – High-volume/speed processing and display technologies – Intelligent software agents – Interoperable databases (cross-queuing, dynamic database fusion) – Human-machine interface – Artificial intelligence • Enhanced human-machine interfaces

4.2.6 Restore Ground Systems for Reuse – *Swab & Reload*



Robust spaceport ground systems with informed maintenance where status of systems is communicated via power-up diagnostics tests that quickly reveal faults and anomalies. Repairs and retests are performed remotely or autonomously without direct user interaction.

Key Characteristics

- **Available, on-demand ground systems**
- **Self-restoring ground systems**
- **Robust ground system**

Concept of Operations

In the Swab & Reload phase of the Plug & Play model, the ground launch systems will continuously report their readiness status and reduce the maintenance requirement to "condition-based" repairs. The ground systems will be designed so they never fail because of their advanced material design, faultless assembly, and ability to detect impending failure. The spaceport support equipment will always be available upon demand.

Historically, the restoration of ground support to accommodate subsequent launches has been a resource-intensive proposition. However, the Swab & Reload phase removes those obstacles that previously impeded an immediate reuse of those ground systems. In this phase, the task of *Restore Ground Systems* is augmented with enhanced automation and artificial intelligence to remove the ground system configuration as the impediment to recurring flights. Swab & Reload systems are engineered with robust, self-restoring attributes that minimize the need for human intervention and external resources to prepare for follow-on ground operations of launch and recovery.

The evolution of capabilities required to perform the Swab & Reload functions is summarized in Figure 27. A more detailed description of the capability evolution can be found in Appendix G.

Challenges

After executing departure operations, the ground systems structures and equipment generally take a beating from the spacecraft's exhaust plume impinging on the structures. Infrastructure interfaces, such as access arms, umbilicals, and the platform, are damaged to the point that extensive refurbishment is required to bring the infrastructure and systems back to an operational condition. Refurbishment operations to recertify systems generally take days to weeks. Visual inspections for material defects, local subsystem functional checkouts, structural reconditioning (e.g., washdown and sandblasting of launch platform) are time-consuming and require specialized handling equipment. These challenges must be overcome if multiple departure operations from the same point are to occur in a day as the vision states.

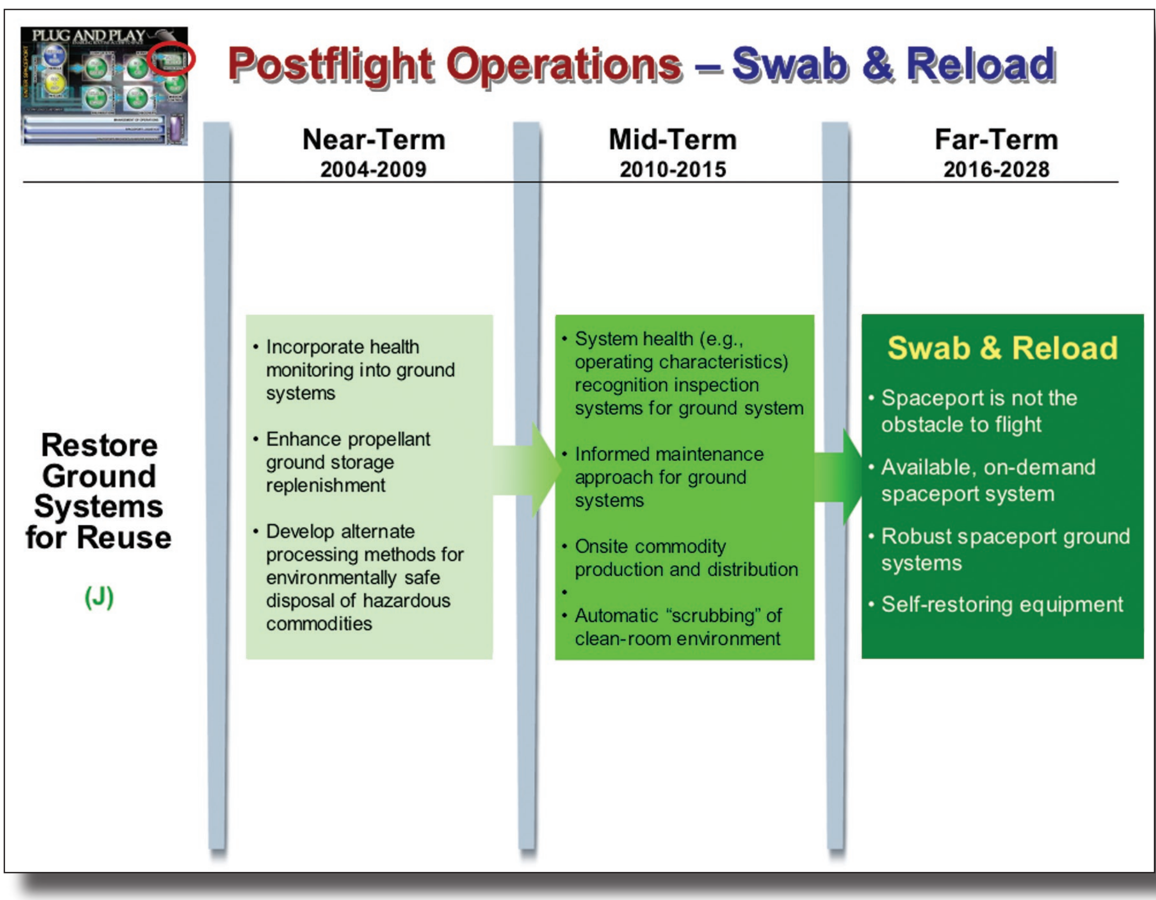


Figure 27. Swab & Reload functional capabilities roadmap summary

Technical Approaches

The technical capabilities required for Swab & Reload include "condition-based maintenance" techniques – maintenance is only performed when needed to avoid system failure. Advanced materials that can survive the rigorous environment after a launch or departure operation will minimize and potentially eliminate the need for massive refurbishment efforts. Depending on the location of the spaceport, corrosion mitigation techniques can also preclude the need for extensive fixed-structure refurbishment. Health management techniques employed within the ground systems can also expedite detection of a nonconformance so repairs are performed rapidly to support multiple launches from the same departure point. Table 8 summarizes the key technologies associated with Swab & Reload. A more detailed description of the challenges and technical approaches can be found in Appendix I.

Table 8. Key challenges and technologies for Swab & Reload

Challenges	Spaceport Technologies
• Unique interfaces create the need for specialized/unique support equipment • Ensuring GSE is available upon demand • Maintaining integrity of ground systems that are exposed to environmental degradation • Reducing /eliminating blast effects on fixed structures	• Advanced planning and scheduling tools – Dynamic scheduling – Situational awareness – Human-machine interfaces – Intelligent software agents • Advanced materials for ground support equipment – Lightweight, high-strength composites – Smart materials • Integrated health management – Neural networks – Artificial intelligence – Adaptive algorithms – Data fusion techniques – Self-diagnostic/remediation techniques • Advanced Sensors – MEMS – Nanotechnology • Nonintrusive nondestructive evaluation techniques – Laser imaging – Robotic inspections • Self-sealing, self-cleaning ground support equipment quick disconnects

4.2.7 Land/Recover Flight and Payload Elements – *Down & Off*

- ***Routine reentry***
- ***Landing with self-safing systems and rapid removal from runway***
- ***Deactivation of landing support systems***

Key Characteristics

- **Spaceport autonomous safing/reconfiguration of the flight vehicle**
- **Autonomous data archive**
- **Quick exit of landing area**

Concept of Operations

Upon completion of the Fly & Play phase of the life cycle, the spaceport prepares for vehicle reentry and arrival. As is typical in the commercial airline industry today, once the vehicle approaches a predetermined point, it is handed off to the spaceport tower for final approach and initial ground control.

The Down & Off phase integrates functions of configuring the vehicle into a "safe mode," disembarking crew and passengers, positioning the vehicle in an appropriate location, and dispositioning time-critical articles (e.g., science specimens, flight data files, limited-life items). In addition, safing steps are accomplished autonomously apart from the vehicle while the ground crew focuses on other processing functions. Other autonomous functions include ground travel management and delivery to the initial parking site at the spaceport.

The evolution of capabilities required to perform the Down & Off functions is summarized in Figure 28. A more detailed description of the capability evolution can be found in Appendix G.

Challenges

Current landing and recovery operations for a reusable launch vehicle pose many challenges that must be overcome if access to space is to become a routine and reliable transportation mode. After the spacecraft returns from orbit and lands at the spaceport, potential hazards include toxic off-gassing from the various propellants and system fluids and the high temperatures of vehicle surfaces caused by reentry into Earth's atmosphere. Prior to allowing the crew/passengers to exit the spacecraft, a hazardous and time-consuming operation to evaluate the environment around the vehicle must be performed. Ground support crews must don protective suits prior to approaching the vehicle, perform a detailed visual inspection around the vehicle, scan the area for toxic gases and hot areas, and finally clear the area for postflight operations to commence. After postflight operations are completed, the vehicle is ready to be transported to its reservicing point, a slow, methodical process because of all the support equipment attached to the vehicle to maintain the proper system conditioning. Efficiencies in landing and recovery operations must be employed so turnaround operations can be compressed.

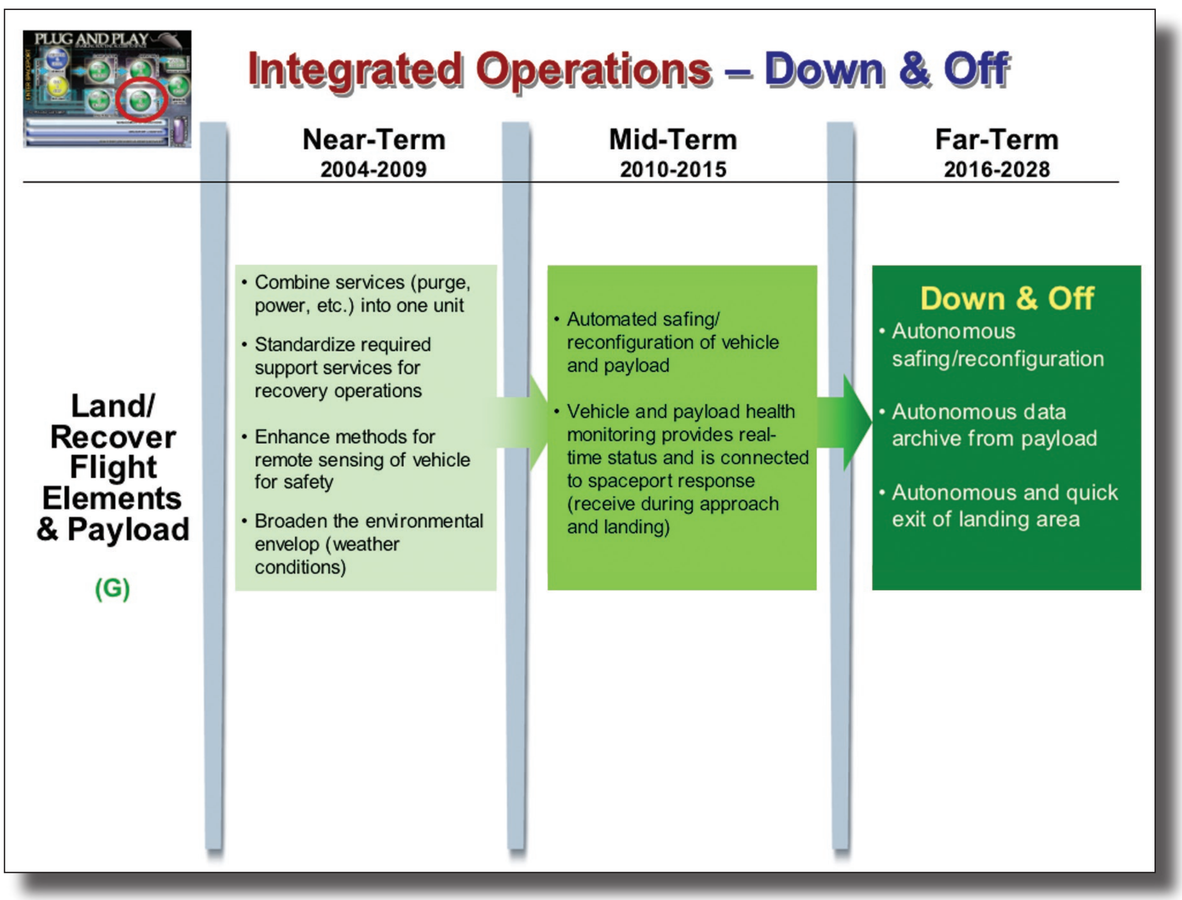


Figure 28. Down & Off functional capabilities roadmap summary

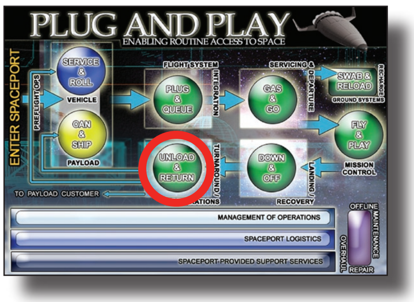
Technical Approaches

The Down & Off phase requires technological capabilities such as advanced imagery systems to scan the vehicle from a safe distance for any hazardous off-gassing and high-temperature conditions after landing. This capability is critical to ensuring a safe environment for both ground support crew and any onboard crew and passengers. Wireless communication with high-bandwidth and data transmission will allow for autonomous download of mission data and vehicle health data, as well as perform autonomous safing and reconfiguration. Table 9 summarizes the key technologies associated with Down & Off. A more detailed description of the challenges and technical approaches can be found in Appendix I.

Table 9. Key challenges and technologies for Down & Off

Challenges	Spaceport Technologies
• Protecting ground workforce, crew, and passengers from potentially toxic hazards and high-temperature structures/surfaces • Manual safing operations are dangerous and time-consuming • Verifying hazards are contained and controlled • Sensing, understanding, and testing vehicle health is difficult and labor-intensive • Transporting unique GSE to "sustain" vehicle systems	• Remote hazardous environment control – Advanced sensing techniques ▪ Spectroscopy ▪ Infrared/ultraviolet ▪ Advanced sensors – MEMS – Nanotechnology ▪ High-bandwidth wireless communications ▪ Artificial intelligence • Nonintrusive nondestructive evaluation techniques – Laser imaging – Robotic inspections • Robotic towing/handling

4.2.8 Turnaround Preparations of Flight Element and Payload – *Unload & Return*



Informed maintenance where status of vehicle is communicated to spaceport via power-up diagnostics tests to quickly reveal faults and anomalies without user interaction.

Key Characteristic

- **Informed maintenance**

Concept of Operations

The Unload & Return phase entails all functions to ready the payload for return to its customer and prepare the vehicle for its next flight. When the vehicle has successfully landed at the spaceport, the cargo is rapidly unloaded and readied for delivery to its final destination using local transportation. At this stage, the cargo is pulled from the bay, taken to a warehouse, unpacked from the universal canister or any vendor-specific transport containers, and given to the customer once inspected and ensured of safe delivery. The payload leaves the premises and the spaceport starts preparing for the next flight.

During the Unload & Return phase, preparing the vehicle to return to service is the top priority. Wirelessly downloading mission files and vehicle health data throughout the mission profile helps the ground crew return the vehicle to service quickly, but a final data transfer will occur at the landing facility. The vehicle will be directed for maintenance, postflight inspections, and testing automatically. Testing will be nondestructive and nonintrusive and will involve minimal human intervention.

The evolution of capabilities required to perform the Unload & Return functions is summarized in Figure 29. A more detailed description of the capability evolution can be found in Appendices E and F.

Challenges

The challenges of Unload & Return are similar to those for Service & Roll or preflight processing operations and include hazardous operations, such as handling residual toxic fuels, and the labor-intensive activities of recertifying subsystems for the next mission. Intensive, intrusive system inspections requiring disassembly lengthen turnaround operation schedules. Special handling equipment is required for disassembly because of the unique nature of all subsystems, which again poses a spaceport maintenance challenge to ensure all equipment is ready for operation. Another critical challenge for turnaround preparations is identifying the subsystems that require repair. This requires the spaceport to accurately track the system configuration of the vehicle both before and after the system repair, as well as to provide just-in-time parts delivery to the turnaround operations area.

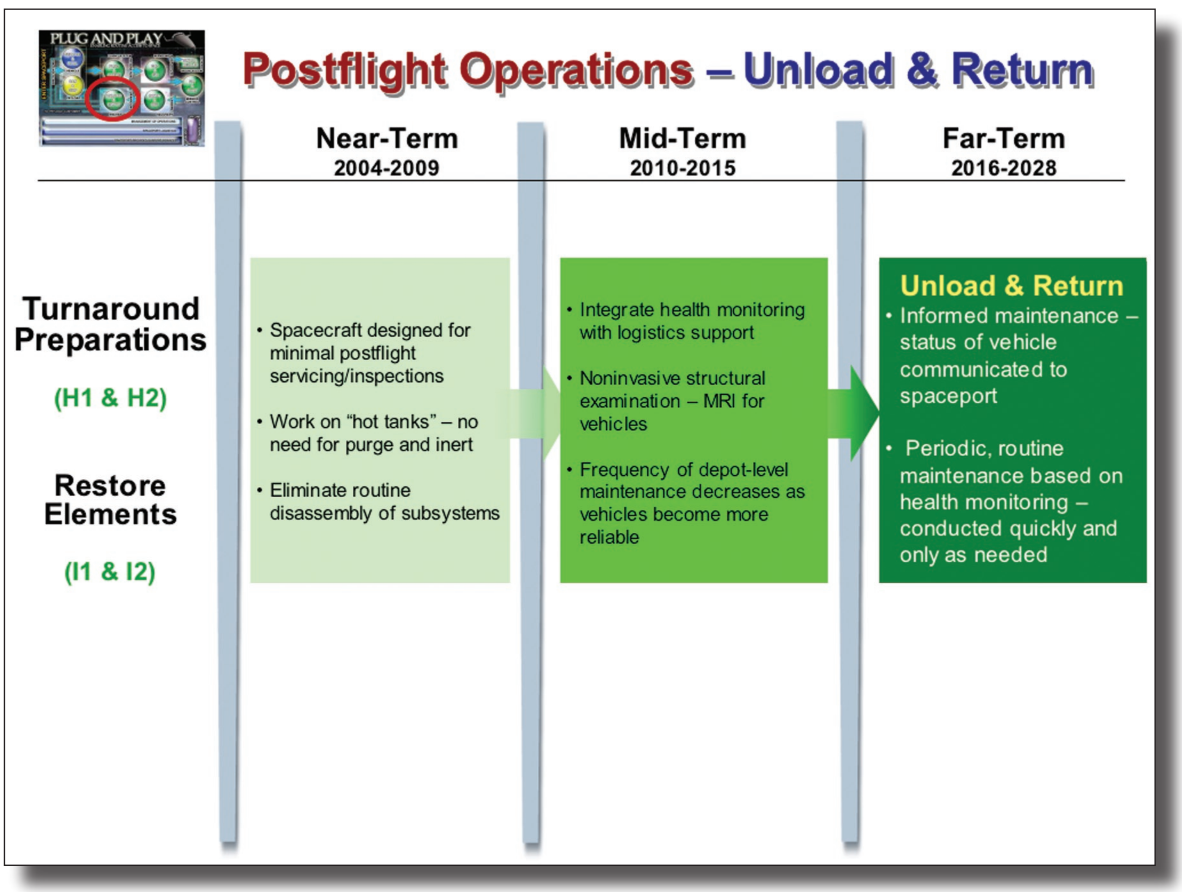


Figure 29. Unload & Return functional capabilities roadmap summary

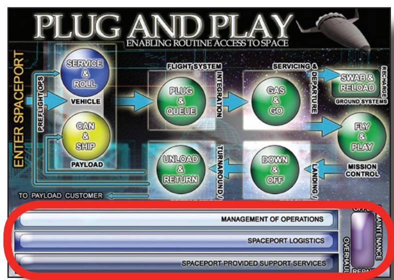
Technical Approaches

Postflight maintenance of the vehicle will be more efficient with turnaround in the order of hours. Maintenance systems will be automated, while vehicle systems will supplement maintenance data through the use of onboard diagnostics and remediation. Maximum use of components and systems requiring no disassembly for inspections and testing will optimize inspection systems that offer anomaly remediation without nested testing requirements. Advanced supply chain management systems will allow for seamless integration to the vehicle health monitoring systems. The required repair part will be available at the operations site upon vehicle return to the spaceport. Rapid return to service is the goal of this phase and is essential to the successful spaceport enterprise. Table 10 summarizes the key technologies associated with Unload & Return. A more detailed description of the challenges and technical approaches can be found in Appendix I.

Table 10. Key challenges and technologies for Unload & Return

Challenges	Spaceport Technologies
• Nonstandard containers and connectors • Unique interfaces require specialized/unique support equipment • Handling of multiple and hazardous propellants is dangerous and requires extensive leak detection • Sensing, understanding, and testing the health of the ground systems is complex, redundant, and intrusive • Ensuring configuration control for next flight	• Nonintrusive nondestructive evaluation techniques – Laser imaging – Robotic inspections • Advanced materials for ground support equipment – Lightweight, high-strength composites • Advanced supply chain management systems – Adaptive algorithms – Data mining techniques – Data fusion techniques • Advanced planning and scheduling tools – Dynamic scheduling – Situational awareness – Human-machine interfaces • Intelligent software agents

4.2.9 Spaceport Logistics – *Assist & Enable*



Efficient, automated, integrated logistics operations that provide effective support for spaceport host, operators, and customers.

Key Characteristics

- **Automated supply chain management**
- **Integrated with vehicle/system health management systems**
- **On-demand materials availability for operators**

Concept of Operations

The Assist & Enable phase ensures operability of all spaceport infrastructure, facilities, and ground support equipment (GSE) to facilitate and support customer requirements. The functional areas include shipping, receiving, acquisition, management of repair, and distribution of customer and spaceport materials, parts, and commodities. In addition, the spaceport may provide customer support for common and unique GSE, infrastructure, and consumables utilized by the operators. Common resources can include materials, consumables, or propellants (e.g., common grade of LO_2, GSE fuels), while unique resources might consist of replaceable parts, spare parts for unique GSE, unique test equipment, or concept flight and ground hardware.

Ideally, the Assist & Enable phase will employ an automated supply chain management system integrated with equipment health management to provide on-demand support of required resources. Services provided by spaceport logistics include rapid, onsite prototyping of generic and space-qualified components, seamless ordering of parts, and a centralized, online repository of component/parts information (e.g., specifications, drawings, maintenance procedures) that is universally available.

The evolution of capabilities required to achieve the visionary goals of Assist & Enable is summarized in Figure 30. A more detailed description of the capability evolution can be found in Appendix H.

Challenges

One of the greatest obstacles to overcome is the lack of concise information that will enable efficient prediction-based maintenance of spaceport systems. The industry has not been effective in collecting maintainability and reliability data. Seamless data collection and analysis is lacking for creation of predictive maintenance systems. Further challenges will include integrating the many specialized information systems that are typically used in contemporary operations.

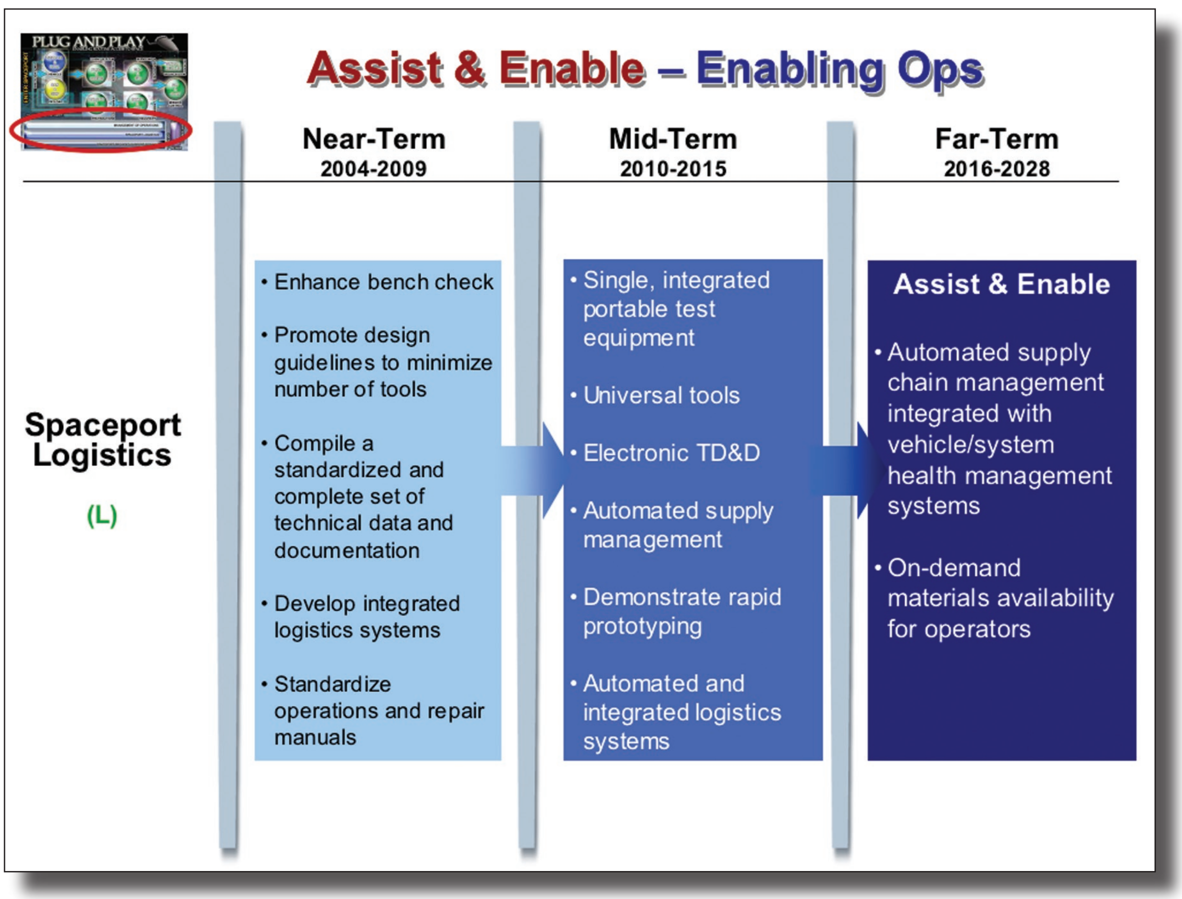


Figure 30. Spaceport logistics functional capabilities roadmap

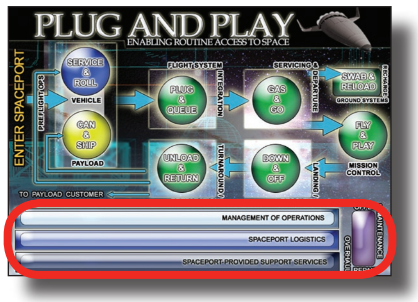
Technical Approaches

The technical capabilities required for Assist & Enable include "condition-based maintenance" techniques – maintenance is only performed when needed to avoid system failure. Advanced materials that can survive the rigorous environment after departure operations will minimize and potentially eliminate the need for massive refurbishment efforts. Table 11 summarizes the key technologies associated with Assist & Enable. A more detailed description of the challenges and technical approaches can be found in Appendix I.

Table 11. Key challenges and technologies for Assist & Enable

Challenges	Spaceport Technologies
• Maintainability and reliability data collection and analysis is lacking for predictive maintenance • Integrating the various information systems • Inadequate testing of new systems • Incomplete documentation and multiple formats/dialects • Injecting maintainability into the flight hardware design	• Interoperable databases (cross-queuing, dynamic database fusion) • Advanced modeling capabilities • Standard data formats • Data mining • Advanced planning and scheduling tools – Dynamic scheduling – Situational awareness – Human-machine interfaces – Intelligent software agents • Data fusion • Taxonomy determination – Intelligent agents • Closed-loop accounting • Autonomous data collection

4.2.10 Management of Spaceport and Flight Operations – *Make It Happen*



All the underlying planning and management that will provide spaceport customers the seamless, transparent service they expect in the course of business.

Key Characteristics

- **Self-service customer interface**
- **Global master planning**
- **Operations and management systems seamlessly integrated and transparent to the customer**

Concept of Operations

The Make It Happen phase requires support for flight and ground systems processing. This includes a variety of host services to plan, manage, and control the operation of the space transportation assets, as well as all elements of the supporting ground infrastructure, systems, and facilities. The services include customer service, strategic management plans, spaceport operations management, business management, engineering, and spaceport safety and health assurance.

Managing the spaceport is a vital role. If the spaceport hierarchy cannot Make It Happen, no one will be able to operate within the boundary efficiently. Strategic planning and budgeting are two key factors that will help provide the spaceport with the knowledge of what to expect in years to come and the ability to adapt. Safety is also paramount at the spaceport, and by evaluating safety risk management and making occupational health checks, the spaceport will ensure safe operating conditions for years to come.

The evolution of capabilities required to achieve the visionary goals of Make It Happen is summarized in Figure 31. A more detailed description of the capability evolution can be found in Appendix H.

Challenges

Operations management must confront the massive and often disjointed volumes of requirements that seem to accompany every new spacecraft and vehicle system. Management of operations lacks good situational-awareness tools for dealing with complex work control and scheduling situations. Systems are needed that can collect information from customers and analyze it to manage spaceport operations; measure operational performance and responsiveness of spaceport systems; coordinate and consolidate spaceport configuration management; and preserve personnel and systems safety. In addition, current operations management functions require extensive paper processing with multiple layers of approval and presentation.

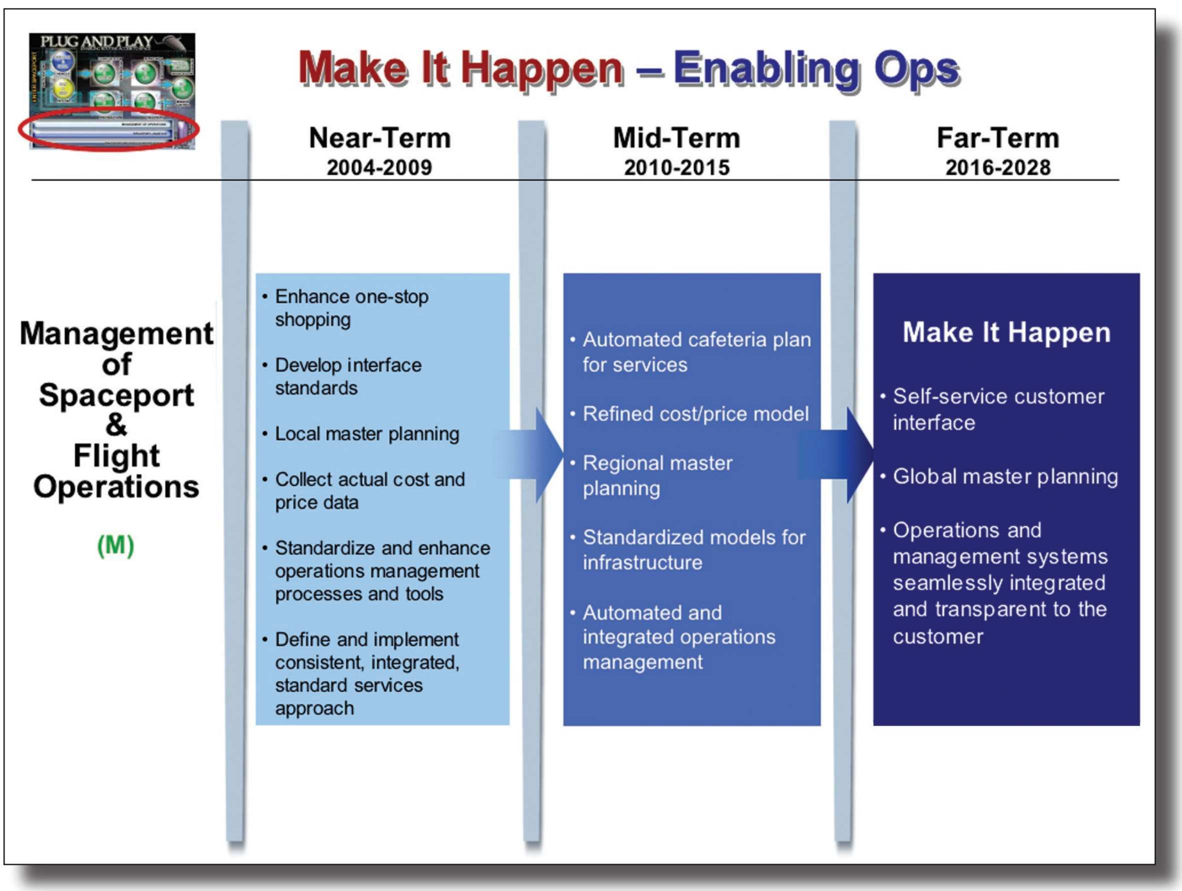


Figure 31. Management of spaceport operations functional capabilities roadmap

Technical Approaches

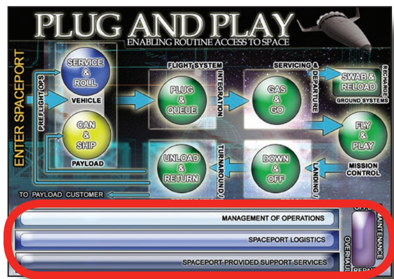
It is envisioned that operations and management systems will be seamlessly integrated and transparent to the customer. All systems will be paperless and available universally. Operations and management systems include but are not limited to data management, decision support tools for safety and risk management, task analysis tools, advanced models and simulation tools, closed-loop requirements tracking, and configuration management. The Make It Happen phase envisions self-service and user-friendly customer service interfaces employing techniques similar to those used in tax-filing software. Table 12 summarizes the key technologies associated with Make It Happen. A more detailed description of the challenges and technical approaches can be found in Appendix I.

Table 12. Key challenges and technologies for Make It Happen

Challenges	Spaceport Technologies

• Large volume of requirements with inconsistent definitions of levels and flowdown
• Lack of situational awareness for work control and scheduling
• Collecting and analyzing management information for spaceport operations
  – Customer
  – Performance
  – Configuration
  – Safety
• Operations management functions require extensive paper processing
	• Advanced planning and scheduling tools
	  – Dynamic scheduling
	  – Situational awareness
	  – Human-machine interfaces
	  – Intelligent software agents
	• Standard data formats
	• Advanced modeling capabilities
	• Data mining
	• Data warehousing
	• Data fusion
	• Taxonomy determination
	• Intelligent agents

4.2.11 Spaceport-Provided Support Services – *Protect & Support*



Mitigating risks to the spaceport and its host community, informing and educating spaceport customers and the general public, and providing expected consumer accommodations and services.

Key Characteristics

- **Just-in-time performance support**
- **Real-time, proactive environmental mitigation – no-waste spaceport**
- **Autonomous surveillance**
- **Seamlessly integrated with global spaceports and customers**
- **Microeconomy within spaceport**

Concept of Operations

The Protect & Support phase consists of services provided to the customer by the spaceport. Some of these services include training/certification (e.g., hazardous material training), environmental management (e.g., monitoring, sensing, and testing hazardous gas), utilities (e.g., power, water, telecommunications, fuel/commodity lines), public outreach and education, and consumer services (e.g., shops, restaurants, entertainment, postal services, money exchange, and hotels).

The evolution of capabilities required to achieve the visionary goals of Protect & Serve is summarized in Figure 32. A more detailed description of the capability evolution can be found in Appendix H.

Challenges

It is often difficult to determine the appropriate maintenance intervals for the many and varied spaceport and vehicle systems. Today's systems are overhauled on fixed schedules based on cycles or flights, timetables that are often based on best-guess methodology. Greater efficiencies will only be found with tools and information that accurately predict the need for maintenance.

Environmental requirements are always a major concern for spaceport operations. Flight systems require toxic chemicals for fuel and prodigious quantities of water to quench flame and suppress noise. They create acoustic problems and, emit environmentally challenging exhaust – and the list goes on.

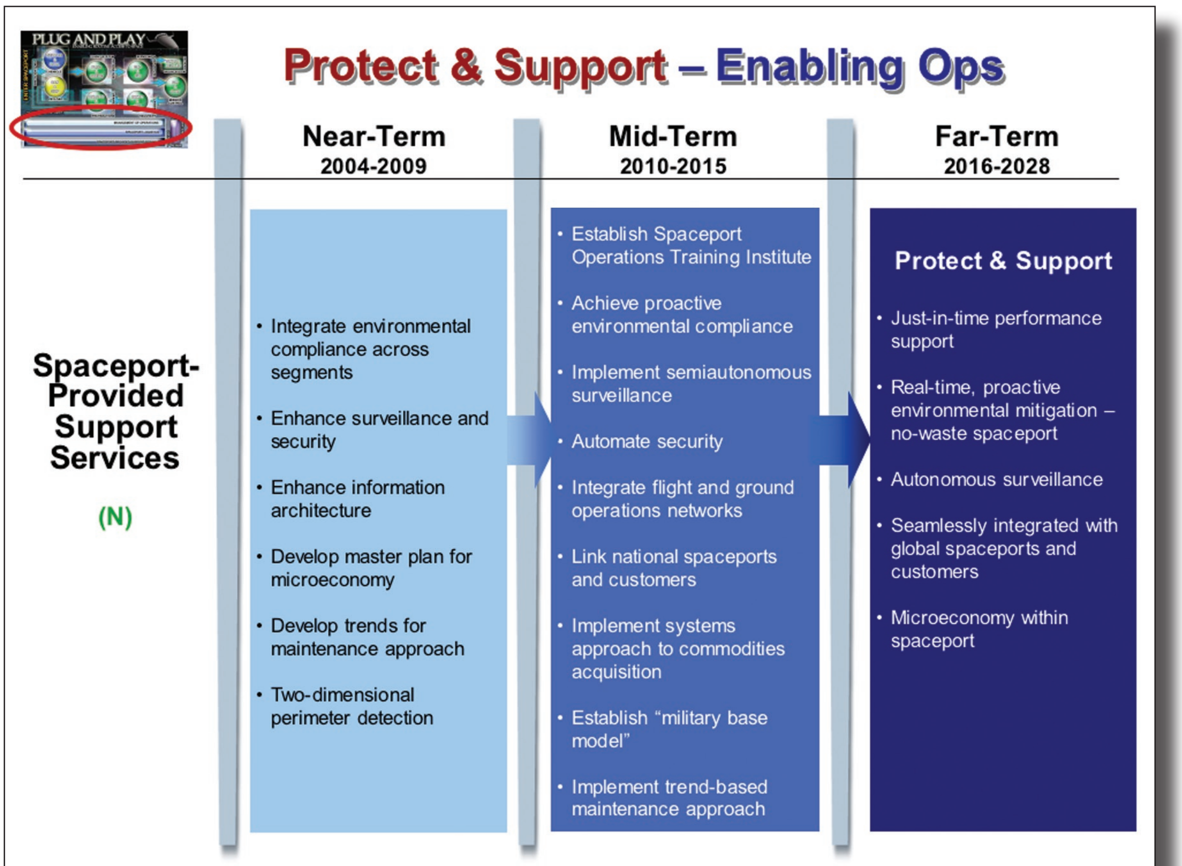


Figure 32. Spaceport-provided support services functional capabilities roadmap

Technical Approaches

Indirect services may be needed to support on-vehicle operations and the local community. Other services required to Protect & Support the customer include security, emergency response, and occupational health services.

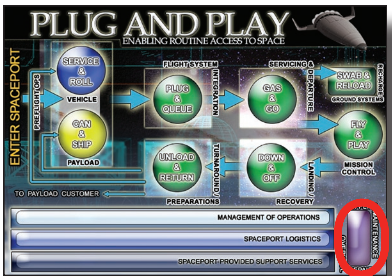
Table 13 summarizes the key technologies associated with Protect & Support. A more detailed description of the challenges and technical approaches can be found in Appendix I.

All three enabling operations (spaceport logistics, management of operations, and spaceport-provided support services) require advanced information management systems that can process and store/archive an immense data set. Data management systems will require standardized data formats as well as employ advanced taxonomy algorithms for data mining exercises. Dynamic scheduling algorithms will allow for real-time scheduling of assets while minimizing disruptions to ongoing or planned operations.

Table 13. Key challenges and technologies for Protect & Support

Challenges	Spaceport Technologies
• Determining the appropriate maintenance intervals • Protecting humans from hazardous operations • Tightening regulations driving environmental management • High cost of moving cryogenic items over a distance	• Data mining • Data fusion • Standard data formats • Advanced modeling capabilities • Taxonomy determination • Intelligent agents

4.2.12 Offline Maintenance, Repair, and Overhaul – *Repair & Refurbish*



Rapid, automated, self-triggered techniques that quickly restore vehicles and ground systems to reliable online service.

Key Characteristics

- **Nonintrusive testing with self-inspecting systems**
- **Self-healing structures and systems**
- **Little or no reassembly**
- **Self-testing and self-healing**

Concept of Operations

The enabling functions also provide the offline maintenance, repair, and overhaul support as dictated by the overall spaceport design. This functionality is characterized by the capabilities associated with nonintrusive inspection and the provision of systems requiring little or no reassembly to effect a repair action. It is supported through automated, self-diagnosing/self-healing systems.

Technologies forecasted to support this functionality include enhanced automation, particularly in the arena of artificial intelligence, as well as standardization of interfaces to support a wide range of hardware applications.

The evolution of capabilities required to perform the Repair & Refurbish functions is summarized in Figure 33. A more detailed description of the capability evolution can be found in Appendix H.

Challenges

It is often difficult to determine the appropriate maintenance intervals for the many and varied spaceport and vehicle systems. Today's systems are overhauled on fixed schedules based on cycles or flights, timetables that are often based on best-guess methodology. Greater efficiencies will only be found with tools and information that accurately predict the need for maintenance.

Performing maintenance on energized and hazardous systems is always a significant safety concern. Better methods need to be found to either eliminate the hazards or further remove the operations personnel from the hazards themselves.

Technical Approaches

Indirect services may be needed to support on-vehicle operations and the local community. Other services required to Repair & Refurbish vehicles and systems include security, emergency response, and occupational health services. Table 14 summarizes the key technologies associated with Repair & Refurbish. A more detailed description of the challenges and technical approaches can be found in Appendix I.

Table 14. Key challenges and technologies for Repair & Refurbish

Challenges	Spaceport Technologies
• Don't design for maintainability or testability • Lack of demonstrated reliability • Specialized/unique support equipment • Complex, redundant, intrusive testing	• Advanced planning and scheduling tools – Dynamic scheduling – Situational awareness – Human-machine interfaces – Intelligent software agents • Standard data formats • Advanced modeling capabilities • Data fusion • Data mining • Taxonomy determination • Intelligent agents

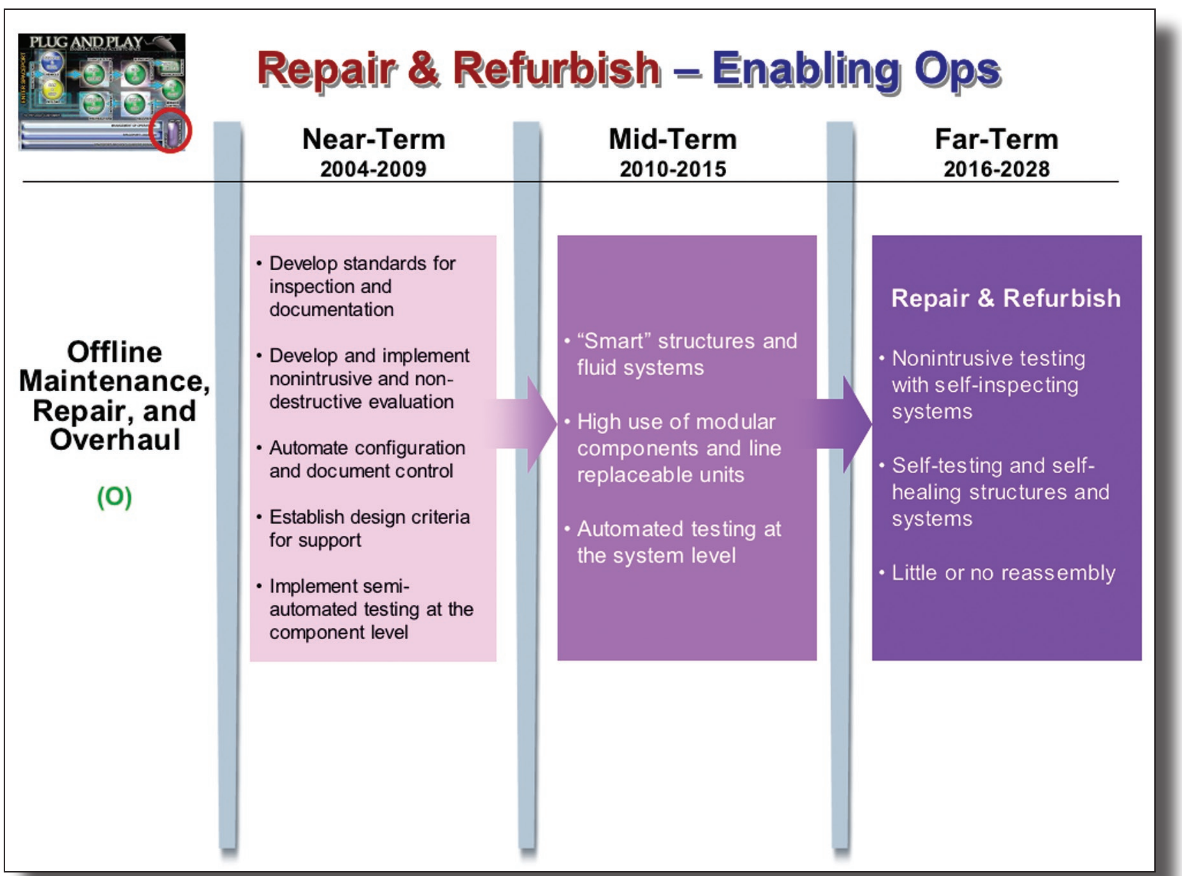


Figure 33. Offline maintenance, repair, and overhaul functional capabilities roadmap